Asian Journal of Surgery (2019) 42, 667–673

Available online at www.sciencedirect.com

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ORIGINAL ARTICLE

Evaluation of anatomical landmarks for transanal total mesorectal excision based on MRI

Zhanlong Shen [a,b,*,1], Jin Cheng [c,1], Mujun Yin [a,b], Kewei Jiang [a,b], Qiwei Xie [a,b], Zhidong Gao [a,b], Yudi Bao [a,b], Yi Wang [c,**], Yingjiang Ye [a,b,***], Shan Wang [a,b]

[a] *Department of Gastroenterological Surgery, Peking University People's Hospital, Beijing, 100044, PR China*
[b] *Laboratory of Surgical Oncology, Laboratory of Colorectal Cancer Diagnosis and Treatment Research, Peking University People's Hospital, Beijing, 100044, PR China*
[c] *Department of Radiology, Peking University People's Hospital, Beijing, 100044, PR China*

Received 29 January 2018; received in revised form 8 October 2018; accepted 19 October 2018
Available online 9 November 2018

KEYWORDS
Transanal total mesorectal excision;
Landmarks;
Anatomy;
Image;
Standardization

Summary *Background:* Transanal total mesorectal excision (taTME) is a novel sphincter-preserving procedure for low rectal cancer. This "bottom to up" approach is unfamiliar to colorectal surgeons and the crucial anatomical landmarks also remain unclear.
Methods: Two hundred and five cases of pelvic magnetic resonance imaging (MRI) from 2015 to 2016 were reviewed. Curvature of posterior mesorectal fascia, distal mesorectal angle, length of posterior mesorectal fascia, main structures around the mesorectum were measured and analyzed. The landmarks identified on MRI were verified in taTME procedures of five rectal cancer patients.
Results: The most of acute angles of posterior mesorectal fascia located at the joint of anococcygeal ligament-coccyx. Degree of distal mesorectal angle was independently correlated with gender and degree of angle of anococcygeal ligament-coccyx. Candidate landmarks evaluated by MRI with verification during taTME procedures included: anterior: seminal vesicle for male while cervix for female. And peritoneal reflection was a substitute landmark when cervix was hardly confirmed in operation; posterior: the joint of anococcygeal ligament-coccyx. The area between the joint of anococcygeal ligament-coccyx and S3–S4 was a "transitional zone", the

* Corresponding author. Department of Gastroenterological Surgery, Laboratory of Surgical Oncology, Laboratory of Colorectal Cancer Diagnosis and Treatment Research, Peking University People's Hospital, Beijing, 100044, PR China. Fax: +86 10 88326608.
** Corresponding author. Department of Radiology, Peking University People's Hospital, Beijing, 100044, PR China. Fax: +86 10 88326608.
*** Corresponding author. Department of Gastroenterological Surgery, Laboratory of Surgical Oncology, Laboratory of Colorectal Cancer Diagnosis and Treatment Research, Peking University People's Hospital, Beijing, 100044, PR China. Fax: +86 10 88326608.
E-mail addresses: shenlong1977@163.com (Z. Shen), wangyi@pkuph.edu.cn (Y. Wang), yeyingjiang@pkuph.edu.cn (Y. Ye).
[1] Zhanlong Shen and Jin Cheng have equal first authorship.

https://doi.org/10.1016/j.asjsur.2018.10.003

level of S3—S4 could be the as the terminal landmark of transanal posterior dissection during taTME.
Conclusions: Preoperative MRI geometrical measurement of mesorectum might play an important role in evaluating the difficulty of taTME procedure before operation, as well as standardizing landmarks during taTME procedure.

1. Introduction

Transanal total mesorectal excision (taTME) is a new approach for surgical treatment of low rectal cancer, which was firstly reported in 2010 by Sylla et al[1] Radical oncologic resection with total mesorectal excision (TME) is currently the standard procedure for middle and low rectal cancer.[2] However, the surgical field of lower mesorectal planes deep in the pelvis may be narrowed by the sacral and coccygeal curvature, especially for patients with contracted pelvises or obesity.[3,4] Impaired visualization during operation may compromise the quality of TME dissection and result in positive circumferential resection margins, especially when the tumor located at the lower third of rectum.[5]

Recently, there is increasing literature that suggest that performing the mesorectal dissection transanally with the help of advanced endoscopic platforms (transanal minimally invasive surgery (TAMIS)[6] or transanal endoscopic microsurgery (TEM)[7]) would provide improved visualization and better dissection compared to the conventional transabdominal TME.[8] Zhang and colleagues published the first case of taTME carried out entirely from below ,[9] shortly followed by Leroy and colleagues.[10] Actually, taTME performed totally from the bottom up is hard to popularize due to its anatomical restriction and technical difficulties.[11,12] Therefore, hybrid technique of transabdominal and transanal approaches for TME dissection was adapted by most surgeons at present. However, the key anatomical structures related to taTME and landmarks between the transanal and transabdominal phases still remain unclear, even though they are very important for surgeons to carry out taTME safely, as well as to standardize and popularize this new procedure. In this study, we collaborated with radiologists and used pelvic magnetic resonance imaging (MRI) to measure crucial anatomical parameters and structures of pelvis and mesorectum, verified these statistics in taTME procedures. We hope this study could provide more information to evaluate the possible difficulties before operation, as well as standardize the procedure and facilitate the learning curve.

2. Methods

2.1. Patients for MRI measurement

This study was approved by our institutional review board (IRB) and in compliance with Health Insurance Portability and Accountability Act (HIPAA). A waiver of informed consent was obtained for this retrospective study. Clinical data were collected from the electronic medical system. Patients undergoing pelvic MRI scans from March 2015 to June 2016 at a single university-affiliated institution were identified. In this part, inclusion criteria were patients without any identifiable rectal cancer pathology (38 cases) or with a rectal/colon mass (167 cases) above the level of the first sacral vertebra. The cases included 87 females 118 males. Exclusion criteria: 1) patients with rectal mass on the middle or low rectum; 2) previous pelvic surgery or radiation therapy before MRI examination, including sacrococcygeal vertebrae, rectum, uterus, or prostate, or if 3) demographic data such as gender, age, height and weight were missing.

2.2. MRI technique and imaging acquisition

Pelvic MRI examinations were performed using 3.0T MR750 scanner (GE Healthcare, Waukesha, WI, USA). Imaging analyses were based on the sagittal and axial T2-weighted fast recovery fast spin-echo (FRFSE) without fat suppression. The parameter of the FRFSE were: repetition time/echo time (TR/TE) = 3619/85 msec (sagittal) and 4170/85 msec (axial); matrix = 320 × 192 (sagittal) and 384 × 224 (axial); slice thickness/gap = 5/0.5 mm; Field of view (FOV) = 27 cm (sagittal) and 30 cm (axial); voxel resolution = 1.5 × 1.5 × 1.5 mm^3; number of excitation = 1.

2.3. Imaging analysis

T2-weighted images were independently analyzed by two board-certified radiologists (10 and 3 years of experience in clinical MRI, respectively). A third board radiologist (20 years of experience in clinical MRI) reviewed the images if the results of measurement were not concordant between the two former radiologists.

2.3.1. Angles measurement along the curvature of the posterior mesorectal fascia

As with conventional TME, the taTME dissection usually begin along the posterior mesorectal fascia (MRF). Posteriorly, the MRF is apposed to the Waldeyer's (presacral) fascia. The curvature of the posterior MRF was therefore approximated by measuring the angle of between sacral vertebral bodies on the sagittal T2WI images (Fig. 1). The most distal portion of the MRF past the distal tip of the coccyx is immediately apposed to the anococcygeal ligament. The curvature of this portion of the distal MRF was

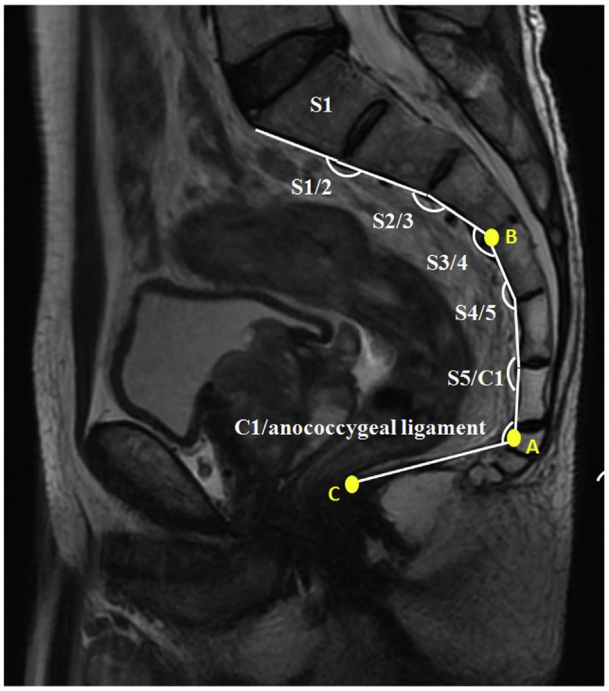

Figure 1 Variables measured on MRI. A 64 years old male patient's sagittal T2WI MR image. The angle between the anterior surface of S1/S2, S2/S3, S3/S4, S4/S5, S5/c1 was 178.1°,162.3°,153.4°, 160.2°and 175.1°, respectively. The angle between the vertebrae surface above the departure point and the anococcygeal ligament was 111.7°. Based on the definition, point A was the departure point which was on the c1 level. Point B was on the S3/4 level. Point C was on the inserted point of anococcygeal ligament to the rectum wall.

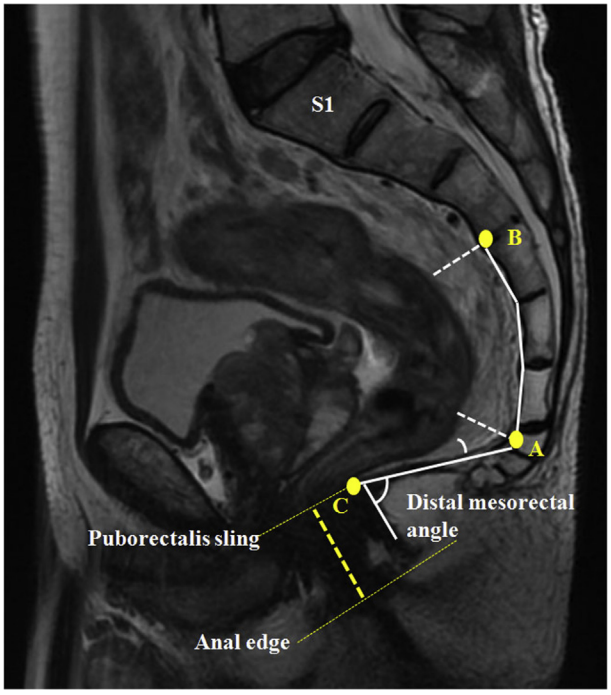

Figure 2 Variables measured on MRI. Line-sum length between point C to point A, and the length of point A to point B were recorded as the length of the posterior mesorectal feascia (white lines). The shortest line segment between point A/B and the posterior wall of the rectum was identified as the thickness of the posterior part of mesorectum (white dash lines). Distal mesorectal angle was identified as the angle between the posterior external sphincter muscle and the anococcygeal muscle (yellow arc).

approximated as the angle between the anococcygeal ligament and the coccyx.

2.3.2. Length measurement of the posterior mesorectal fascia

The length of the posterior mesorectal fascia was calculated by measuring the distance from the pubo-rectal sling (the inserted point of anococcygeal ligament to the rectal wall, named as point C) to the apical point of most acute angle (named point A) and from point A to the apical point of less acute smallest angle (named point B) along the posterior mesorectal fascia. The shortest line between point A and B and the posterior wall of the rectum was identified as the thickness of mesorectum at these two points (Fig. 2).

2.3.3. Distal mesorectal angle

taTME dissection usually begins with a purse string suture 1—2 cm distal to the tumor. For very distal tumor, this often occurs at the top of the surgical anal canal. The surgeon must then perform a full-thickness transection of the rectum and mesorectum at this level, then identify the correct MRF plane and proceed upwards. The angle of between the distal MRF and the anal canal (as measured by the posterior anal wall) was measured and defined as the distal mesorectal angle (Fig. 2).

2.3.4. Identification anatomical landmarks during taTME by MRI

Anterior and lateral structures were identified at the point with most acute angle along the posterior rectal fascia on the transverse section of MRI. these structures should be visible or at least touchable during the operation, and could

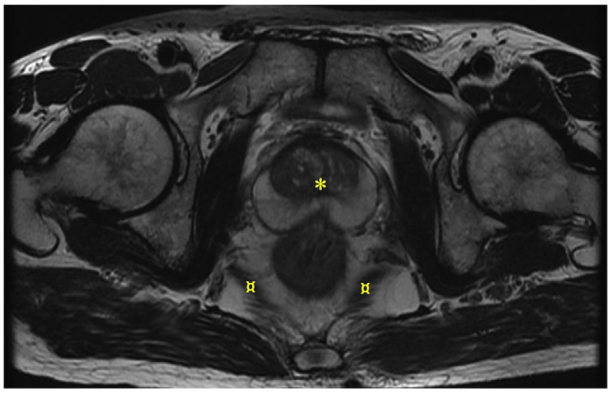

Figure 3 Main structures at point A on transverse section of MRI. the Axial T2WI image at the level of point A by using cross-reference technique. The structures anterior and lateral to the rectum at this level are the prostate (*) and the muscles levator ani muscle (¤).

be recommended landmarks of between transanal and abdominal phases during taTME procedure (Fig. 3).

2.3.5. Verification of candidate landmarks of two phases during taTME operation recommended by preoperative MRI

The anatomical landmarks between transanal and transabdominal phases identified on MRI were verified in six patients (3 males and 3 females) underwent taTME procedures. taTME procedures were carried out based on the recommended landmarks by preoperative MRI in three patients (2 males, 1 females), trananal approach stopped once landmarks were reached, and then transabominal approach started from the top down until met with transanal phase. In three male patients (2 males, 1 females), transanal approach was performed beyond the recommended landmarks from the bottom up until sacral promontory on the posterior, peritoneal reflection was reached on the anterior. All transanal approaches in six patients were performed by one operator, transabdominal approaches were performed by three operators coming from same medical group, who had more than ten years of experiences in laparoscopic rectal surgery. The transanal and transabdominal approaches were performed simultaneously by two teams. The quality of mesorectal excision was graded by a surgeon who didn't attend the operation. The grading was classified into three classes: good, intact mesorectal plane; morderate, intramesorectal plane and poor, muscularis plane[13]. After operations, questionnaires about the rationality and feasibility of landmarks were collected from surgeons. This got approved by our institutional ethical board (Fig. 3).

2.4. Statistical analysis

Data were expressed as means ± SD. Independent *t*-test was used to evaluate differences in variable measurements. Linear regression was use to analyze the correlation between variables. P values were considered significant at the $P < 0.05$ level. The variables with statistically significant differences were entered into the multivariate analysis. Multivariate liner regression was used to evaluate the independent predictors for key anatomical parameters. All statistical analyses were performed using SPSS version 17.0 (SPSS Inc., Chicago, IL, USA).

3. Results

3.1. Angles between sacrums, coccyx and anococcygeal ligament

Mean angle between anococcygeal ligament and coccyx was significantly smaller than that of angle of S1—S2 ($P < 0.001$), S2—S3 ($P < 0.001$), S3—S4($P < 0.001$), S4—S5($P < 0.001$) and S5—C1($P < 0.001$) in all 205 patients. Angle of anococcygeal ligament-coccyx in female was significantly larger than that in male (mean degree: 17.2 ± 1.8 *vs.* 13.7 ± 1.3, $P = 0.041$). Mean degree of angle of S3—S4 was significantly larger than that of angle of anococcygeal ligament-coccyx ($P < 0.001$), but smaller than that of other angles: S1—S2 ($P < 0.001$), S2—S3 ($P = 0.002$), S4—S5 ($P = 0.097$), S5—C1 ($P < 0.001$) (Table 1). Multiple regression analysis showed that age ($P = 0.004$) was an independent factor of the degree of angle of anococcygeal ligament-coccyx, the angle was smaller in younger patients compared to older ones (Supplementary Table 1).

3.2. Degree of distal mesorectal angle

Mean degree of distal mesorectal angle was 98.9 ± 17.3 in all patients. The degree of distal mesorectal angle in female (mean degree:) was significantly larger than that in male (mean degree: 102.9 ± 14.6 *vs.* 96.1 ± 18.6, $P = 0.005$). The degree of distal mesorectal angle was markedly correlated to gender ($P = 0.005$, $P = 0.013$) and the degree of angle of anococcygeal ligament-coccyx ($P = 0.006$, $P = 0.016$) in both univariate and multiple regression analysis (Supplementary Table 2).

3.3. Distance between point C, point A and point B along the posterior fascia of mesorectum

Mean of distance from point C to A in female was significantly longer than that in male (5.7 ± 1.7 cm *vs.* 5.0 ± 0.7 cm, $P < 0.001$). Multiple regression analysis showed that gender ($P = 0.001$) was an independent determinant factor for the distance from point C to A (Supplementary Table 3).

Mean distance from point A to B in female was immensely shorter than that in male (4.0 ± 1.9 cm *vs.* 4.6 ± 1.8 cm, $P = 0.015$), which is statistically negative correlated with the distance from C to A ($P = 0.001$). Age was an independent factor of the distance from point A to B in multivariate analysis ($P = 0.001$), the older patients had longer distance from A to B than younger ones (Supplementary Table 4).

3.4. Main structures around the mesorectum at the site of most acute angle (point A) on transverse section of MRI

The anterior structure was most often the lower edge of seminal vesicle or the upper part of prostate in male cases, the lower part of cervix or the upper part of vagina in female cases; the posterior structure was the joint of anococcygeal ligament-coccyx in all cases; the lateral was the middle part of levator ani muscle in most cases (Table 2).

Table 1 The degree of angles between sacrums, coccyx, and anococcygeal ligament.

The angles between vertebras along the posterior fascia of mesorectum	Mean Degree
S1～S2	169.4 ± 7.7
S2～S3	164.4 ± 8.1
S3～S4	160.9 ± 9.6
S4～S5	162.8 ± 8.8
S5～C1	169.6 ± 14.4
Coccyx-anococcygeal ligament	122.4 ± 16.8

Table 2 Main structures around the mesorectum at the site of most acute angle (point A) on transverse section of MRI.

Male (n = 118)		Female (n = 87)	
Anterior			
Seminal vesicle	69.5% (82/118)	Cervix	80.5% (70/87)
Upper edge	8.5% (7/82)	Upper part	28.6% (20/70)
Middle part	24.4% (20/82)	Middle part	34.3% (24/70)
Lower edge	67.1% (55/82)	Lower part	37.1% (26/70)
Prostate	30.5% (36/118)	Vaginal	19.5% (17/87)
Upper part	50.0% (18/36)	Upper part	88.2% (15/17)
Middle part	36.1% (13/36)	Middle part	11.8% (2/17)
Lower part	13.9% (5/36)	Lower part	0% (0/17)
Posterior			
Joint of anococcygeal ligament-coccyx	100% (118/118)		100% (118/118)
Lateral			
Levator ani muscle	100% (118/118)		97.7 (85/87)
Upper part	17.0% (20/118)		26.4% (23/87)
Middle part	80.5% (95/118)		71.3% (62/87)
Lower part	2.5% (3/118)		0% (0/87)
Piriformis muscle			2.3% (2/87)

3.5. Verification of candidate landmarks between transanal and transabdominal phases during taTME operation

Candidate landmarks during taTME procedures were evaluated by preoperative MRI based on above method: seminal vesicles (4 males) or cervix (2 females) on the anterior, joint of anococcygeal ligament-coccyx on the posterior (all 6 patients). The specimen of all six patients were good (4 cases) or moderate (2 cases) qualities. Questionnaire showed that all operators considered: (1) recommended landmarks by MRI were reasonable during taTME procedures; (2) seminal vesicle as the anterior landmark for male was visible and feasible, but cervix for female was difficult to confirm from the trananal phase, peritoneal reflection might be the substitute; (3) joint of anococcygeal ligament-coccyx could be the first posterior landmark of transanal approach for male and female, which could be touched, but hardly visible during posterior dissection, the level of S3/S4 could be another landmark of posterior dissection, the dissection became hard after crossing which (Fig. 4).

4. Discussion

As a novel surgical approach, taTME[14] has been described as a ''solution to an old problem'' for patients with low rectal cancer.[2] However, transanal approach from bottom up during taTME procedure is a challenge for surgeons, preoperative anatomical geometry evaluation and measurement by imaging might help perform this technique safely and decrease the complications. Moreover, the landmarks between transabdominal and transanal phases during taTME remains unclear, still requiring the standardization of this new technique.

As Dr. Atallah described, taTME dissection was performed along the facia in front of curving sacrum which shaped like the capital letter "L", and the horizonal potion of rectum was the best approach from the in-line vantage point of transanal access, while the upper rectal dissection was best approached transabdominally.[13] Therefore, the heel of the "L" could be the optimal landmark between transabdominal and transanal phases base on this conception, but the location of the heel of "L" -shape remains unclear. Ferko et al reported CT/MRI pelvimetry as a tool to predict if the patients of rectal cancer could benefit from taTME.[15] MRI had shown better capability to identify the pelvic structures such as mesorectal fascia, muscles and glands compared to computed tomography (CT) scan.[16,17] In this study, we used MRI pelvimetry to explore the anatomical variables and landmarks during taTME procedures.

We found that the angle of anococcygeal ligament-coccyx was most acute along the posterior mesorectal fascia in all patients. This is the likely point that the conventional transabdominal TME dissection becomes difficult due to severely impaired visualization of surgical fields, especially in patients with unfavorable pelvises. In our study, six patients were gathered to verify the recommend landmarks by preoperative MRI, we found that posterior landmark (joint of anococcygeal ligament-coccyx) could be reached by both of transanal and transabdominal approaches, and it was easier via the former one. Moreover, transanal dissection became difficult at the second acute angle (level of S3—S4), whereas it was easy to be crossed by transabdominal dissection. Given the findings of this study, we speculated that joint of anococcygeal ligament-coccyx could be as the posterior landmark between two phases of taTME procedure, transanal dissection should proceed beyond this point at least, but it was not visible easily, just could be touched. The area from joint of anococcygeal ligament-coccyx to S3—S4 might be as a "transitional zone", which could be entered by two approaches, it became hard after crossing this level from transanal approach, but it could be reached effortlessly from transabdominal approach. Therefore, the S3—S4 might be recommended as the last stop of transanal approach during taTME.

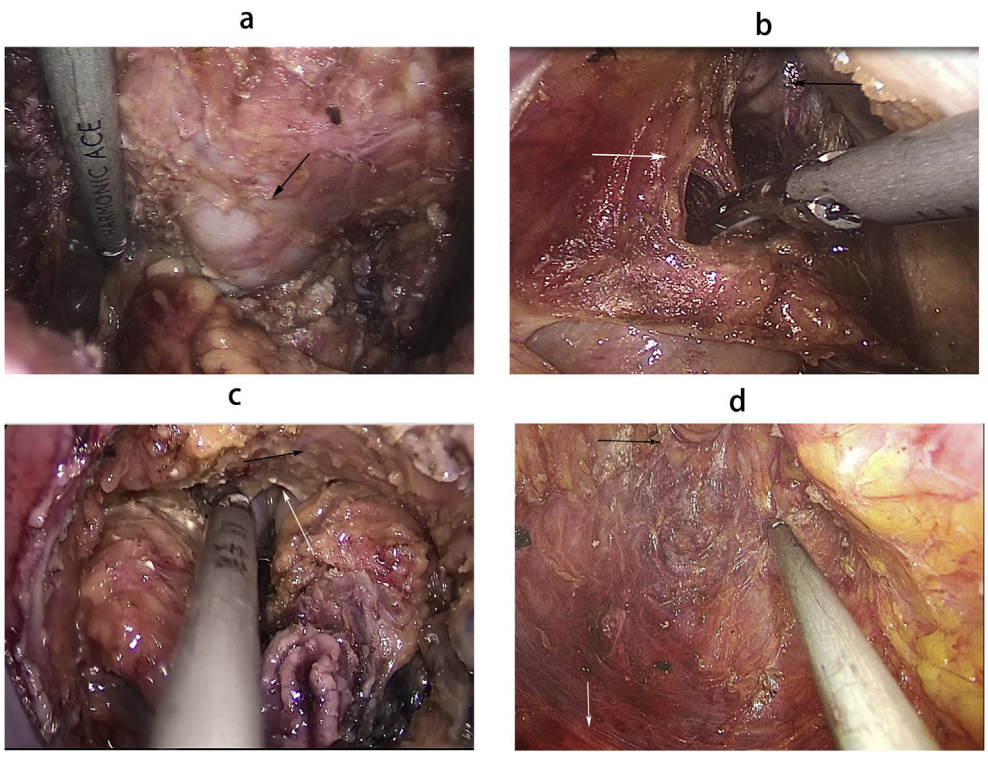

Figure 4 Surgical field during taTME. a. A male patient, the anterior dissection stopped at the level of seminal vesicle in transanal phase. Seminal vesicle (black arrow), which is seen from transanal approach; **b.** A female patient, the transanal approach stopped when the peritoneal reflection was reached, the peritoneal reflection was opened by transabdominal approach. Seminal vesicle (black arrow), peritoneal reflection (white arrow), which were seen from transabdominal approach; **c.** A male patient, the peritoneal reflection was dissected by transanal approach. Seminal vesicle (black arrow), peritoneal reflection (white arrow), which were seen from transanal approach; d. A female patient, posterior dissection along the sacral curvature. The black arrow was the sacral promontory, the white arrow was the level of S3—S4.

The evaluation by MRI showed that the candidate anterior landmark between transanal and transabdominal phases was usually at the seminal vesicle in males and the cervix in females. However, in the surgeries for verification, the cervix was not easy to find from transanal approach compared to the seminal vesicle during taTME procedures. Peritoneal reflection which covered the cervix at Douglas pouch might be the substitute of cervix as the upper border of transanal dissection. We don't recommend opening the peritoneal reflection before the posterior landmark reach, because the pelvic pneumoperitoneum pressure may be decreased, making the exposure of transanal phase impaired. Therefore, anterior dissection by transanal approach might better stop at the level of the seminal vesicle in males or the peritoneal reflection in female, which both more optimal and visible landmarks compared to the posterior landmark of joint of anococcygeal ligament-coccyx in the operation.

The correct dissection plane is essential for the rectal cancer surgery for avoiding uncontrolled bleeding and nerve injury.[18,19] Preoperative assessment of the inclination of distal mesorectum from the distal to the proximal is crucial to help follow the "Holy" plane during taTME.[20] We named the angle between the posterior fascia of distal mesorectum and the posterior wall of anal canal as the distal mesorectal angle in our study, which could represent the inclination of posterior dissection plane during taTME. We found that the degree of distal mesorectal angle was highly correlated to gender as an independent determinant factor. The degree of distal mesorectal angle in female was significantly larger than that in male. The distal mesorectal angle is smaller, the route of transanal posterior dissection is steeper. Therefore, the transanal dissection for male might require more caution to expose the posterior plane by pushing the mesorectum cephalad and anterior with greater strength.

Preoperative measurement of the distance between crucial points along the posterior mesorectal fascia might throw light on taTME procedure. The awareness of landmarks of most acute angle (point A) and second most acute angle (point B) were very important for posterior dissection during taTME, it could help us understand where we might have reach, when we could arrive at the last landmark. In this study, we found that the distance from point C to A was negative correlated with the distance from A to B. Moreover, gender was an independent determinant factor of distance from point C to A. Mean distance from point C to A in female was significantly longer than that in male. This could be explained by the wide pelvis and pelvic floor in female. It indicated that we might face a longer journey to get the first posterior landmark (joint of anococcygeal ligament-coccyx) in female compared to male, but might have shorter way then to last stop (S3/S4). Limitation of this study are as followed: this study mainly concentrated

on parameters affecting anterior and posterior approaches during taTME, however, parameters affecting dissections of sidewall were almost not assessed.

In summary, preoperative geometrical evaluation during taTME procedure by MRI, such as Identifying and assessing the degree of distal mesorectal angle, crucial structures and landmarks, might play an important role in prior evaluation of the difficulties of operation, decrease of postoperative complications, and standardization of this new procedure. Recommend landmarks based on this study: anterior: seminal vesicles for male, cervix or peritoneal reflection for female; posterior: joint of anococcygeal ligament-coccyx, area from joint of anococcygeal ligament-coccyx to S3—S4 was a "transitional zone" for transanal and transabdominal phases, the level of S3—S4 could be the last stop of transanal approach during taTME.

Conflict of interest

No conflict.

Acknowledgement

We are appreciated that Dr. Sam Atallah gives us great comments on the manuscript, Dr. Lawrence Lee contributes to the polish of the language of manuscript. Dr. Sam Atallah and Dr. Lawrence Lee are the doctors of Center of Colon & Rectal Surgery, Florida Hospital, Winter Park, FL, USA. This study was supported by grants from The National Natural Science Foundation of China (81672375), Beijing Municipal Natural Science Foundation (7182171), Clinical Medicine Plus X - Young Scholars Project of Peking University (PKU2018LCXQ021).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.asjsur.2018.10.003.

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